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(56) Documents cited
GB 2029393 A GB 1602968 A GB 1489819 A
GB 1471091 A GB 0999578 A GB 0973121 A
US 4507336 A

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(54) **Method for attenuating gas diffusion through a structure**

(57) A structure (10) is coated to form a continuous shell (22) that prevents gas from diffusing through the structure (10). The shell (22) is preferably a rigid polyurethane foam material having a closed cell structure with a density between 2.5 and 3.5 pounds per cubic feet. The low bulk diffusion rate coefficient of the foam acts to trap the gas in the cells of the foam rather than permitting the gas to pass through the structure (10).

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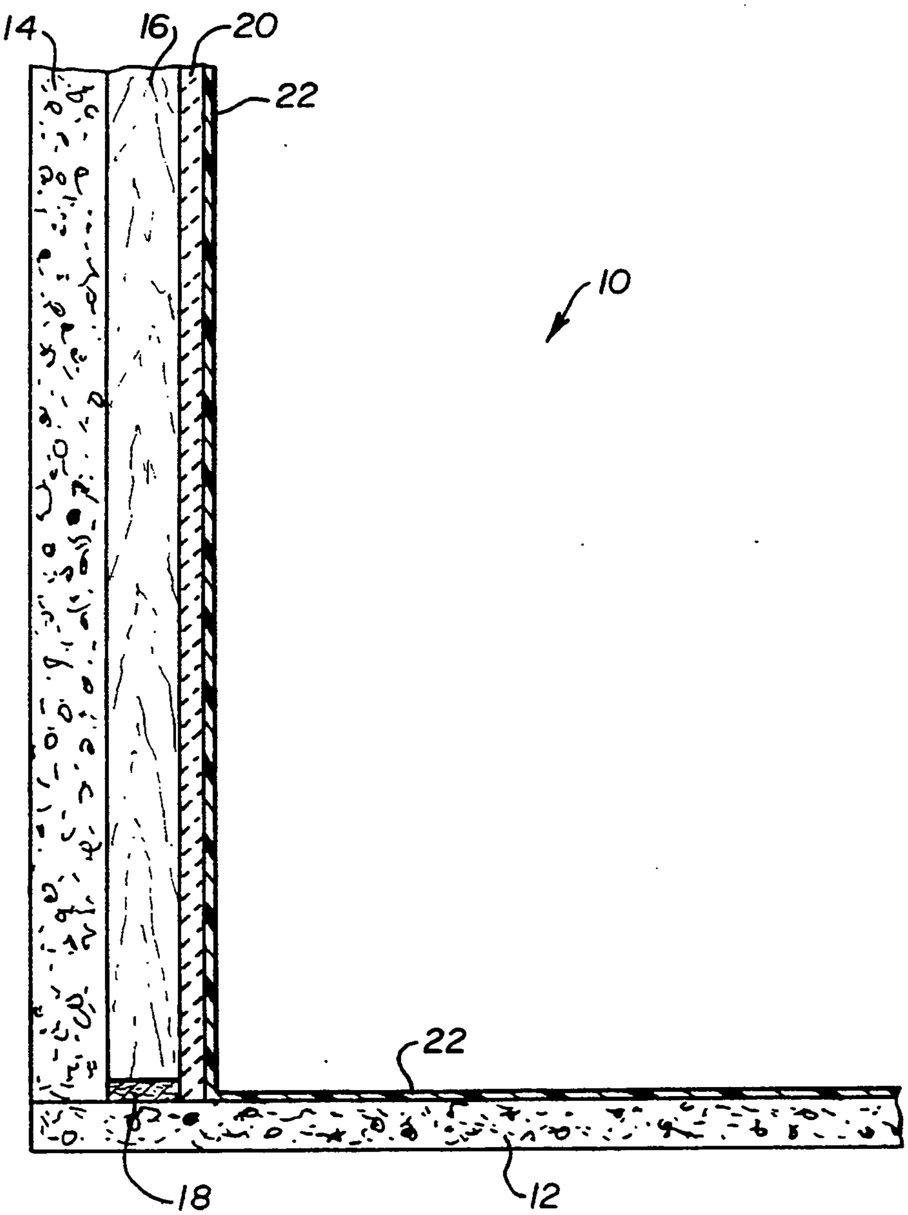

FIG_1

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METHOD AND APPARATUS FOR ATTENUATING GAS DIFFUSION THROUGH A STRUCTURE

This invention relates to a method and apparatus for attenuating radon gas and radioactive decay product diffusion through a structure, and, more specifically, coating the surfaces of a structure with foam to form a continuous shell by which radon gas and radioactive decay product diffusion is retarded.

Retarding gas diffusion through a structure is desirable because of environmental, health and safety factors. One widely discussed and studied gas is radon which can be found in the ground surrounding the foundations of homes and in residue storage silos or waste pits found at uranium ore processing installations. Storage silos are generally man-made units and are further discussed below. Waste pits generally are existing openings in the ground, often times the mines from where the uranium ore is removed. The waste is pumped back into the mine and a clay or concrete cap, approximately five feet in thickness, is placed over the openings.

Preventing radon from diffusing into residential dwellings is important for health and safety reasons. Those of ordinary skill in the art will appreciate that exposure to radon above certain levels will increase a person's risk of getting lung cancer.

At industrial installations, it is important to attenuate radon from diffusing through residue storage silos or waste pits and into the atmosphere. Once airborne, the radon will disperse and decay within several kilometers of the silo or pit. Since the radon disperses, the level of radon cannot be detected above background level; that is, the level of naturally occurring radon. It would be impossible to determine whether the radon level is due to the residue storage facility or the naturally occurring radon. People residing within several kilometers of the silo or pit could be exposed to elevated levels of radon, raising environment, health and safety concerns.

Conventional methods for preventing the diffusion of radon gas through a storage silo into the atmosphere involves coating the silo with clay or like material or even concrete. However, the required thickness of the clay or concrete layer to prevent radon diffusion can, in most instances, exceed several feet, which may be prohibitive from an economical viewpoint. Further, using clay or concrete would necessitate the construction of a silo which would be smaller than desired because of structural considerations in forming the clay or concrete layers. If a larger silo is desired, a supporting structure may be necessary to prevent the silo from collapsing upon itself due to the added weight of the clay or concrete layer. The thickness of the clay or concrete layer to attenuate radon gas diffusion may not make it possible to form a continuous shell of the clay or concrete on the surface of the silo. The presence of any cracks or voids in the clay or concrete layer will lessen the effectiveness of radon gas attenuation.

If preventing radon gas from entering the basement of a house or similar structure is desired, coating the walls and floor with additional concrete or clay would neither be feasible nor economically viable. If clay or concrete were used to coat the walls and floor of the basement, usable living space would be severely

diminished. Digging around the foundation of the house or building to put a thick layer of concrete or clay between the ground and the foundation would be economically prohibitive. Also, it is impossible to place concrete or clay under the supporting concrete slab of the basement without resulting structural damage to the slab or building.

It is therefore an object of the invention to provide a method for coating the surfaces of a silo or building to prevent the diffusion of radon gas through those structures. It is a further object that the resulting shell be cost effective, fill all voids and cracks in the surfaces, provide a continuous shell covering the surfaces of the structure, and apply easily to the surfaces of the structure.

This invention provides a method and apparatus for attenuating radon gas and radioactive decay product diffusion through a structure. A coating is applied to the surface of the structure, forming a continuous shell of the coating on the surfaces. The shell attenuates diffusion of the gas through the structure by retaining substantially all the gas in the shell. Preferably, the shell is a rigid polyurethane foam having a rigid closed cell structure.

The invention has the advantages of being easy to apply, fills all cracks and voids in the surface, thereby providing a continuous shell and is cost effective.

The invention will become more readily apparent from the following description of the preferred embodiment thereof, shown by way of example only, in the accompanying drawing wherein:

Figure 1 shows a cross-sectional view of the shell, mounted on the wall and floor of a structure, constructed according to an embodiment of the invention.

Figure 1 shows a partial, cross-sectional view of room 10. Concrete floor 12 and concrete wall 14 form the surfaces of room 10. Those of ordinary skill in the

art will appreciate that concrete floor 12 and concrete wall 14 can be constructed out of brick and mortar or any other similar construction material. Framing members 16 and 18, commonly constructed from wood or metal, are securely attached to concrete wall 14 and concrete floor 18, respectively, using various fasteners, for example, nails, screws and bolts. A covering 20 may be mounted to framing member 16 and 18 once the framing members are securely attached to the floor and wall. Covering 20 may be wood paneling or gypsum board, commonly called drywall. The drywall may be coated with paint or wallpaper to provide a more livable atmosphere. Those of ordinary skill in the art may also appreciate that the basement of a house may consist just of concrete wall 14 and concrete floor 12, commonly called an "unfinished basement". Shell 22 covers entirely concrete floor 12 and covering 20. It will be appreciated that, if framing members 16 and 18 and covering 20 were not present, shell 22 would cover concrete wall 14 and concrete floor 12.

The coating that forms shell 22 is sprayed on the surfaces in order to form the shell. Preferably, the coating is a rigid polyurethane foam material, having a rigid closed cell structure. The foam material is self-adhesive and has excellent insulating properties. Spraying the foam material fills any cracks or voids in the surface.

Prior to forming shell 22, it is recommended that the surfaces to which the coating will be applied be cleaned to remove dirt and any loose particles. If the dirt or loose particles are not removed, imperfections might result in the formed shell 22, disrupting the continuous nature of the shell. These imperfections might prevent a continuous shell to be formed, necessitating patching of the imperfection site or removing the shell and recoating the surfaces.

Those of ordinary skill in the art will recognize that the polyurethane foam is a two-component coating system. Those of ordinary skill in the art will

also appreciate that the equipment required to apply a two-component coating system is commercially available from several manufacturers. One such manufacturer is Foam Enterprises Research, based in Minneapolis, Minnesota.

The two components that comprise the coating system, generally a polyol and a diisocyanate, are pumped from their respective containers through flexible hoses into a spray gun. The components are mixed in the spray guns and blown onto the surfaces to be coated using a blowing agent. Preferably, the blowing agent is a fluorocarbon; for example, trichloromonofluoromethane. The operator applying the coating can control the thickness of the coating by adjusting the flow rates of the components and by adjusting the distance between the spray gun and the surface to be coated. The components react upon mixing but the coating reaches the surface prior to formation of the foam. The foam formed is rigid and stable in structure. Spraying the components permits a continuous shell to be formed.

The shell may also be formed by pouring the components onto the surface to be coated. The components are first mixed together with a blowing agent and then poured onto the surface to be coated. A continuous shell is also formed.

In Fig. 1, shell 22 is continuous and there is no joint present in shell 22 where covering 20 abuts floor 12. Preferably, the foam density is between 40 and 56 kilograms/m^3 (2.5 and 3.5 pounds/ft^3). The foam density can be controlled by adjusting the flow rates of the components and the pressure of the blowing agent.

The foam may also be applied in the space between wall 14 and covering 20 that is bounded by framing members 16 and 18, if it is desired not to cover covering 20 with foam for aesthetic reasons. The operator would bore a hole through covering 20, being careful not to bore into framing member 16 or 18. Using the spray method described above, the nozzle of the spray gun is inserted into the bore and the coating is sprayed onto the inner

surface of wall 14. While the majority of the inner surface of wall 14 would be covered, the area of wall 14 where framing members 16 and 18 abut would not be covered by the foam. Floor 12 would be coated separately from the inner surface of wall 14. It is also possible to apply the coating by first mixing the components together and pouring the coating through the bore. As the coating reacts and forms the foam, it will expand and fill the space. A continuous shell would not be formed by either spraying or pouring the foam through the bore, resulting in less than full attenuation of radon gas diffusion when compared to a continuous shell directly placed on covering 20 and floor 12; that is, shell 22.

The preferred polyurethane foam is sold under the trade name MG2-B, available from Foam Enterprises Research, Minneapolis, Minnesota. MG2-B is an isocyanate-polyether and polyester triol system. The polyurethane foam produced is a rigid, closed cell structure. Advantages of using foam that forms closed cells are compression resistance, excellent adhesion and thermal insulation (low rate of heat transmission). Because closed cell foam resists compression, it is possible to walk directly on a floor coated with the foam without damage to the foam. If desired, a flooring surface, for example, tile or carpet, can be applied directly to the exposed foam surface to provide an aesthetic and comfortable walking surface. Additionally, wall coverings, such as wallpaper or paneling, can be mounted directly on the foam covering the walls. If a painted surface is desired, it may be necessary to install an undercoating having a smooth surface, on top of the foam surface, to obtain a smooth surface suitable for painting.

The closed cell structure acts to attenuate radon gas diffusion. The radon diffuses through the wall, floor or other section of the structure. Upon contacting the foam, radon diffuses into the closed cells of the foam and diffuses in and out of the closed cells of the foam. Because of the low bulk diffusion rate coefficient of the

foam, as discussed herein below, a long time is needed for the gas to diffuse from one cell and into another cell. Since a long time is needed to diffuse, the radon will decay into harmless products before it can diffuse through the foam barrier and either into or out of the particular structure. Radon, with a half-life of approximately 3.82 days, decays to form a solid particle of Pb^{210}, which further decays to elemental lead (Pb). Those of ordinary skill in the art will appreciate the mechanism by which radon decays to elemental lead. The size of the solid particles is on the molecular level and will not clog the foam cells.

Although the discussion above is concerned with attenuating radon diffusion through the floor and walls of a basement in a dwelling, it may equally apply to storage silos or waste pits containing residue from uranium ore processing installations. Those of ordinary skill in the art will appreciate that the thickness of the foam needed in a storage silo or waste pit will be greater than that required for a dwelling because the level of radon is generally much greater in a storage silo or waste pit than in the ground surrounding a dwelling.

As discussed above, a silo or waste pit can be used to store the waste residue. A storage silo is generally cylindrical in nature, constructed from steel reinforced concrete and has a domed cover also constructed from steel reinforced concrete. A typical silo is 24.4 meters (80 feet) in diameter and approximately 8.3 meters (27 feet) in height. The cylindrical portion of the silo is usually surrounded by an earthen embankment, leaving the concrete dome above ground and exposed. Generally, the silos are designed to be filled with a metal oxide slurry containing radioactive residues. The residues settle to the bottom of the silo and the water is decanted for reuse in producing additional slurry.

Since the dome of the silo is above ground, it is subjected to the weather effects of the sun, wind, rain and other meteorological phenomena. The concrete dome is

prone to cracking or failure due to exposure to weathering elements. Any cracking or failure of the dome could potentially cause release of a large quantity of radioactive gas into the atmosphere. Thus, the use of foam, sprayed onto the interior surface of the dome would attenuate gas diffusion, even if the dome is cracked. If the dome were to completely fail, the foam would be strong enough to maintain the integrity of the silo until emergency crews arrive to seal and contain the radioactive residue and adequately repair the silo.

Covering the interior surface of the dome with foam involves a process similar to that discussed above with regard to covering the floor and walls of a basement. The foam components are supplied from a bulk tanker, in a split feed arrangement, to a distribution van. The van contains equipment that is used to control the flow rate of the components. Flexible hoses are connected to the van and transfer the components from the van to a portable spray gun. The silo dome has effluent manholes and the spray gun is inserted through the manholes so that access to the interior surface of the dome may be had. The components are mixed at the spray gun and a blowing agent is used to blow the foam into the silo. The operator can control the directional flow of the foam with the spray gun.

Theoretical calculations were performed to determine whether foam would be used to attenuate radon diffusion through a silo dome. Those of ordinary skill in the art will appreciate that similar calculations can be done with regard to the walls and floor of a dwelling as discussed above. Calculations were performed for two cases: a silo without a covering, and a silo with a foam covering. The radon flux from the bare tailings source (the uncovered silo), J_O, is calculated using the following equation:

$$J_O = 1 \times 10^4 \, [Ra]pE(tD_O/P_O)^{0.5} \qquad (1)$$

Equation (1) is equation (16) as defined in United States Nuclear Regulatory Commission, "Final Generic Environmental Impact Statement on Uranium Milling," NUREG-0706, Volume III, Appendix D, September, 1980 ("NUREG-0706"). In Equation (1):

[Ra] = Concentration of Radium-226 in the tailings solids (pCi/g)

p = Density of the tailings solids (g/cm^3)

E = Emanating power of tailings (Dimensionless)

D_O = Effective bulk diffusion coefficient for radon in the tailings (cm^2/sec)

P_O = Porosity or void fraction in tailings solids (Dimensionless)

t = Decay constant for radon-222 (sec^{-1})

The diffusion length of the tailings must be found before (D_O/P_Ot) in Equation (1) can be solved. The diffusion length is defined as:

$$L = [D_O/P_Ot)]^{0.5} \qquad (2)$$

Equation (2) is taken from T. B. Borak, Report on "Calculation of Radon Emission, Dispersion and Dosimetry from K-65 Storage Tanks at the Feed Materials Production Center," Fernald, Ohio, October, 1985 ("Borak"). The following values of [Ra], p, E and L are also taken from Borak:

[Ra] = 2×10^5 pCi/g

p = 1.6 g/cm^3

E = 0.2

L = 150 cm

t, decay constant for radon-222, which may be found in several sources well known to those of ordinary skill in the art, is 2.1×10^{-6} sec^{-1}.

Knowing t, the value of D_O/P_O can be, and, thus J_O

$$L = [(D_O/P_Ot)]^{0.5} \tag{2}$$

$$D_O/P_O = L^2t \tag{3}$$

$$= 4.73 \times 10^{-2}\ cm^2/sec$$

With D_O/P_O known, J_O can be calculated from Equation (1):

$$J_O = 2.0 \times 10^5\ pCi/m^2sec$$

Since the radon flux of the bare tailing source, J_O, is known, it is possible to determine J_1, the radon flux from the surface after attenuation with the foam cover using Equation (4):

$$J_1 = J_Of\ Exp(-b_1x_1) \tag{4}$$

Equation (4) is defined in NUREG-0706 where:

$$f = 2/[(1 + Z) + (1 - Z)Exp(-2b_1x_1)] \tag{5}$$

$$z = P_O/P_1[D_O/P_O)/(D_1/P_1)]^{0.5} \tag{6}$$

$$b_1 = (tP_1/D_1)^{0.5} \tag{7}$$

x_1 = Thickness of cover material (cm)

P_1 = Porosity of cover material (Dimensionless)

D_1 = Effective bulk diffusion coefficient for radon in foam (m^2/sec)

From various literature references known to those of ordinary skill in the art, P_1 and D_1 are given as follows:

$$P_1 = 0.95$$

$$D_1 = 1 \times 10^{-6}\ cm^2/sec$$

x_1, taken from Borak, is 300 cm.

Substituting P_1, D_1 and t (as discussed above) into Equations (5) through (7), b_1 and f can be calculated:

$$b_1 = 1.42\ cm^{-1}$$

$$f = 0.029$$

Knowing b_1, f and x_1, J_1 can be calculated using Equation (4).

$$J_1 = 0$$

Thus, based on the above assumptions, no diffusion of radon through the foam will occur.

Because of the general construction of domes, it is very possible that the foam height may only be 61 cm. Calculating J_1, using X_1 = 61 cm at certain areas on the dome.

$$b_1 = 1.42\ cm^{-1}$$

$$Exp(-b_1X_1) = 2.68 \times 10^{-38}$$

Since $Exp(-b_1X_1)$ is approximately zero, a 61 cm thickness of foam will essentially attenuate radon gas diffusion from the silo.

The above discussion is a theoretical approach to determining whether foam would attenuate radon diffusion through the silo. Laboratory experiments were performed to determine the effectiveness of polyurethane foam to attenuate the diffusion of radon gas in order to validate the theoretical calculations above. Essentially, charcoal canisters were placed over containers initially filled with various amounts of radium bearing residues, then subsequently filled with foam. The effectiveness of the foam to attenuate diffusion of radon gas was determined by comparing the activity of charcoal canisters exposed to the radium residues with and without foam present between the residues and the canisters. Two experimental tests were performed.

The first test performed used four 150 milliliter plastic containers containing radium residues of 26, 36, 40 and 45 grams, respectively. The radium residue was taken from an actual silo sample obtained from the Department of Energy's Feed Materials Production Center, Fernald, Ohio, in the early 1970s. The foam material used in the experiments is similar to the proposed closed cell polyurethane and was obtained from a hardware store. To

obtain a base line of expected radon daughter activity that could be absorbed into the charcoal canisters, a charcoal canister was taped onto the open end of each sample container. The charcoal canisters used were approximately 7 cm in diameter and 2.54 cm in height. The opening in the charcoal canister was faced toward the residues and the charcoal canister was taped securely to the containers. Approximately 3.81 cm of air space existed between the charcoal canister and the residues. After 24 hours of exposure to the residues, the charcoal canisters were removed and counted for beta/gamma activity utilizing a Ludlem rate meter and a pancake probe. In addition, a reference canister, exposed to the laboratory surroundings was maintained to determine if any natural radon was present. The sample containers were then injected with the polyurethane foam material and new charcoal canisters taped onto the sample containers before the foam cured. The charcoal canisters were exposed to the residues for various lengths of time, then removed and counted for beta/gamma activity. The results from test one are presented in Table 1 below. The sample numbers one through four refer to the residue weight, 26, 36, 40, and 45 grams, respectively. The foam column is labelled with either a yes if the container sample contained foam, or no if just air was present between the residues and the charcoal canisters. The exposure time (hours) of the charcoal canisters is listed for each test. The last column in Table 1 lists the activity in counts per minute (CPM), above background, beta/gamma radiation measured immediately after the charcoal canister was removed from the containers. The charcoal canisters were counted several times after the initial count to verify that the activity was due to radon daughters and not long-lived contamination from the residues.

TABLE 1

TEST #1 RADON ATTENUATION RESULTS

Sample	Residue Wt (gm)	Foam	Exposure Time (hrs)	CPM (beta/gamma)
1	26	No	24	1120
1	26	Yes	66	290
2	36	No	24	2280
2	36	Yes	24	50
2	36	Yes	41	210
3	40	No	24	2420
3	40	Yes	66	0
4	45	No	24	2820
4	45	Yes	19	310

The second test performed used two 1400 milliliter glass containers each containing 100 grams of residue. The same procedure was followed described previously, by counting the charcoal canisters for absorption of radon gas initially without any foam. Several differences existed, however, between the first test and the second test. After the initial 24-hour exposure of the charcoal canisters to the 100 gram sample of residues, the samples were injected with foam and the foam allowed to cure before new charcoal canisters were placed onto the containers. The reason that the foam was allowed to cure before the canisters were placed onto the containers is that activated carbon has a definite affinity for organic vapors released during curing of the foam and may have become nearly saturated with the vapors before absorption of the radon gas began in the first test. In addition, an air space between the top of the foam and the charcoal canisters was maintained.

The results from test two are presented in Table 2 below. The sample numbers five and six both contained 100 grams of residues in a 1400 milliliter glass container.

The initial test without any foam present in the containers are marked with a "No" under the foam column in Table 2. The exposure time for samples five and six were

the same for the foam and the no foam tests. The last column, counts per minute (CPM) is the same as in Table 1.

TABLE 2

TEST #2 RADON ATTENUATION RESULTS

Sample	Residue Wt (gm)	Foam	Exposure Time (hrs)	CPM (beta/gamma)
5	100	No	24	9000
5	100	Yes	240	0
6	100	No	24	9500
6	100	Yes	240	0

From the data presented in Tables 1 and 2, it can be seen that in all instances, the addition of foam between the residues and the charcoal canisters attenuated the diffusion of radon gas into the canister. Samples 1, 2 and 4 in Table 1 showed evidence of radon gas adsorbing onto the charcoal with the foam in place. The activity from these samples, however, is concluded to have been caused by leakage of the radon gas around the foam or through cracks and not by diffusion through the foam. The reason for this conclusion is that the foam thicknesses present on top of the residues in test one varied between 2.5 and 3.8 cm, which is the minimum thickness that a seal could be obtained in the 150 milliliter containers. Therefore, it is suspected that positive seals were not obtained for samples 1, 2 and 4.

During test two, the size of the container was increased to allow for additional foam thickness. The weight of the residues was also increased to increase the radon flux from the residues. The results from test two showed that no diffusion of radon gas occurred through an average foam thickness of 5.6 cm. The use of glass container in test two allowed a visual observation of the foam seal which appeared to be good.

The results of the tests performed show that a closed cell polyurethane foam, when properly sealed, totally attenuates the diffusion of radon gas. The critical parameter from the data appears to be the

integrity of the foam seal over the radon producing residues. Good attenuation was still provided, however, in the cases where a total seal was not obtained.

Radon diffusion coefficient measurements were performed on four samples of polyurethane materials to provide independent verification of the attenuation abilities of foam by Rogers and Associates Engineering Corporation ("RAE"), Salt Lake City, Utah.

The samples were prepared by Foam Enterprises Research at their Houston, Texas, facility using sample holders supplied by RAE, and were then returned to RAE. The sample holder is a tube of polyvinylchloride (PVC) approximately 15 to 20 cm long and 2.5 cm in diameter. A 10 cm thick plug of the foam to be tested is placed in the middle of the tube such that the tube is divided into two sections, the plug separating one section from the other. The tube was inserted into a radon diffusion chamber. A radon source was placed in one section of the tube and a radon detection system was placed in the opposite section. Radiation counts over a period of time were taken and diffusion coefficients were measured using procedures outlined in "Technical Approach Document," United States Department of Energy, Uranium Mill Tailings Remedial Action Project DOE/UMTRA-050425, May, 1986. RAE is an approved Environmental Protection Agency Laboratory, as defined in Title 40, Code of Federal Regulations, Parts 1 et seq. Results of the diffusion coefficient measurements appear in Table 3 below:

TABLE 3

Sample Type	Bulk Diffusion Coefficient (cm^2/sec)
Elastomer Foam (FE7053)	4.4×10^{-6}
Elastomer (FE9039)	380×10^{-6}
Flexible Foam (FE7090.05)	740×10^{-6}
Rigid Foam (MG2-B)	4.0×10^{-6}

The foam listed in Table 3 above are available from Foam Enterprises Research under the trade names listed therein.

Radon attenuation and surface flux calculations were made using RAECOM, a computer program, outlined in V. C. Rogers, K. K. Nielson and D. R. Kalkwarf, "Radon Attenuation Handbook for Uranium Mill Tailings Cover Designs," NUREG/CR-3533, April, 1984, using the measured diffusion coefficients, reference values for the residues and cover composition and thickness. The source data used are:

Radium Content	2×10^5 pCi/g
Density	1.6 g/cm^3
Emanating Power	0.2
Porosity	0.3

The cover configuration and calculated surface flux values determined by RAECOM appear in Table 4 below:

TABLE 4

Material	Center Section Thickness (cm)	Edge Section Thickness (cm)
Radium Residue Source	150	150
Elastomer Foam (FE7053)	5	5
Elastomer (FE9039)	61	61
Flexible Foam (FE7090.05)	91	183
Rigid Foam (MG2-B)	213	0

Surface flux (pCi/m^2sec): Center = 2.4×10^{-8}
Edges = 1.6×10^{-3}

The use of foam to attenuate radon gas diffusion (void space filling) is considered to be a feasible alternative over water column absorption, solid media absorption and temperature control. The following assumptions were used to develop the alternatives listed above:

- annual diffusion of Radon-222 through the dome
- annual release of Radon-222 by expansion of the gas within the dome
- inability of dome to hold significant pressure above or below atmospheric pressure
- temperature fluctuation of silo gas phase similar to ambient temperature fluctuations

- interim solution (3 to 5 years) to radon emission control needed until final plans are developed and implemented
- domes are structurally weakened by environmental factors and have limited capacity to support additional heading
- method used to attenuate radon emissions should be removable if final plans dictate

Water column absorption is used in many applications to control the emission of gaseous pollutants by allowing the effluent gas to interface the water and be absorbed by the water. Success of the water column absorption is dependent upon the solubility of radon gas in water as compared to the other gases present. It is predicted that the radon gas is indeed soluble enough in water to enable the control of its emission from the silos. The water column system would consist of a vent line leading into a continuously moving water column. The replenishment of the water column is necessary so that the water does not become saturated with the gases. The water would then need to be held in a tank until the radon activity had decayed to an acceptable level. After radon decay, the water would be degassed and the remaining nonradioactive gases would be vented to the atmosphere. The degassified water would then be recirculated into the water column to absorb vented gases from the silos. The critical design concerns associated with this system would be the efficiency of the water column to absorb radon gas, the quantity of water required, flow rates, shielding requirements, and waste-water treatment requirements. The use and construction of the apparatus required for water column absorption is well known to those of ordinary skill in the art.

Solid media adsorption as a separation process has been effectively used to preferentially remove gaseous components from a flow stream. The system would consist of a filter-blower unit that would draw gas from one of the silo manholes, through a vent line and circulate the

gas through an activated carbon bed where the radon gas would be adsorbed. The remaining gases would then be circulated back into the opposite side of the silo dome to complete the closed system. Additional activated carbon beds would be piped in parallel to one another so that once saturation of the carbon beds occurred, as determined by downstream gas sampling, valves could be activated to isolate the saturated carbon bed and circulate the gas to a fresh carbon bed. Some of the important factors that would need to be considered in the design of such a system would be the adsorption efficiency of the activated carbon beds, the total adsorption capacity of a given carbon bed before saturation occurs, flow rate requirements and shielding requirements. The use and construction of apparatus required for solid media adsorption is well known to those of ordinary skill in the art.

Using foam to cover the interior surface of the dome is described in detail above. Filling the void space above the residues in the silos with a rigid polyurethane foam material would serve to remove the existing reservoir that the radon gas currently accumulates above the residues. In addition, the foam material would act as a diffusion barrier to trap the radon gas that diffuses from the residues and hold up the radon gas until it decayed into its respective, particulate daughter products, thus never allowing the radon gas to escape into the environment. In order to accomplish the silo void space filling, the foam material would have to be pumped into the silos through the four existing manholes on the silo domes. A temporary system such as the water column absorption or the solid media adsorption system could be utilized to treat the initial volume of radon gas displaced by the void filling system. The most critical design concerns associated with the void filling system is the structural impacts of the foam, the compatibility of the foam with the residues and the effective sealing ability of the foam material.

A temperature control system for the silos would maintain the gas contained within the silos at a constant temperature, thereby eliminating the escape of radon due to a temperature increase and subsequent expansion of the gas. The system would consist of a filter-blower unit that would draw gas from one of the silo manholes, through a vent line, and circulate the gas through a cooling unit that would cool and maintain the silo as at a near constant temperature before returning the gas back to the silo. The thermostatic control of the cooling unit would have to be adjusted with seasonal variations in the temperature to avoid excessive cooling requirements. The most critical design requirement for this system would be the flow rate and the cooling unit capacity. The use and construction of apparatus required for temperature control is well known to those of ordinary skill in the art.

The evaluation of the four radon emission control alternatives discussed above was based on a numerical ranking from 1 (least acceptable) to 5 (most acceptable) concerning the following criteria:

- Environmental Acceptability (EA)
- Reliability/Operability (R/O)
- Implementation Time (IT)
- Cost ($)

The results from the ranking are presented in Table 5 below:

TABLE 5

RANKING OF RADON EMISSION CONTROL ALTERNATIVES*

Alternative	EA	R/O	IT	$	Total
Water Column Absorption	4	2	2	3	11
Solid Media Adsorption	4	2	2	3	13
Void Space Filling	4	5	4	2	15
Temperature Control	2	2	4	3	11

*1 = least acceptable
5 = most acceptable

A definition of each of the ranking criteria and justification for the ranking assignments is explained below.

The environmental acceptability of an alternative was determined by estimating the ability of an alternative to reduce radon emissions with the least environmental impact. Factors such as expected treatment efficiency and waste generation from the treatment systems were considered. The goal in implementation of the radon emission control systems is to reduce the exposure to the nearest off-site resident to less than 25 mrem (whole body) dose and 75 mrem (critical organ) does as determined by dispersion modeling. The previous dose limits are listed in Title 40, Code of Federal Regulation (CFR), Part 191. Although the material is not by definition a transuranic or high-level waste as defined by 40 CFR 191, it is the goal to maintain the material to the previously defined dose standards.

Generally, referring to Table 5, alternatives 1, 2 and 3 were considered equivalent in terms of environmental acceptability. The efficiency in treating radon emissions to below the 25 mrem/75 mrem standards is considered obtainable for alternatives 1, 2 and 3 due to the fact that both the diffusion and thermal release of radon would be decreased by the alternatives. The

temperature control system was rated lower than the other alternatives because this system would not reduce the radon gas concentration in the silo domes and therefore not reduce the radon emissions due to diffusion. Although the void space filling alternative may potentially increase the volume of waste to be disposed of in the future, the added benefit for dome structural reinforcement enhances its environmental acceptability.

The reliability/operability of an alternative was determined by an estimate of how well the given system would function for a period of three to five years and an estimate of maintenance and operability requirements. The three to five year period was chosen to reflect the time required before final remedial actions could be designed and implemented. The most reliable and operable alternative was determined to be the void space filling system. Although a temporary radon treatment system is required prior to the void space filling, it was decide that over a three to five year period, that this passive alternative would be substantially more reliable and operable than the other three alternatives.

The other three alternatives were equally ranked well below the void space filling system, anticipating that each of the other three alternatives would require considerable maintenance to remain reliable. The implementation time was determined by estimating the required time that an alternative would require for design and construction to operate as a radon emission control system. Alternatives 2, 3 and 4 were all equally ranked for implementation time, estimated at six months, due to the relative simplicity and available technology for each of the three systems. The water column absorption alternative was ranked well below the other alternatives due to the estimated longer design time (12 months) caused by the lack of commercially available systems for the particular application.

The cost of an alternative is an order of magnitude estimate of the total cost for the alter-

native considered. Overall, all of the alternatives are considered approximately equal as far as total cost is concerned. The void space filling was estimated to have a higher loss than the other three alternatives due to the added up-front cost of the fill material and the potential removal costs of the fill material.

CLAIMS:

1. A method for attenuating radon gas and radioactive decay product diffusion through a structure (10) comprising the steps of:

applying a coating to the surface (12, 20) of the structure (10), thus forming a continuous shell (22) of said coating on said surface (12, 20), said method characterized in that said shell (22) that is formed attenuates diffusion of the gas through the structure (10) by retaining substantially all the gas in said shell (22).

2. The method of claim 1 further characterized in that said continuous shell (22) is formed of a rigid polyurethane foam, said foam having a closed cell structure.

3. The method of claim 2 further characterized in that said continuous shell formed of polyurethane foam has a density of between 40 and 50 kilograms/meter^3.

4. The method of claim 2 further characterized in that said foam has a bulk diffusion rate coefficient between 1 x 10^{-4} and 1 x 10^{-7} cm^2/sec.

5. An apparatus for attenuating radon gas and radioactive decay product diffusion through a structure (10) comprising a shell (22), said shell (22) formed by applying a continuous coating to the surface (12, 20) of the structure (10), characterized in that said shell (22)

by retaining substantially all the gas in said shell (22).

6. The apparatus of claim 5 further characterized in that said coating is a rigid polyurethane foam, said foam having a closed cell structure.

7. The apparatus of claim 6 further characterized in that said polyurethane foam has a density of between 40 and 56 kilograms/meter^3.

8. The apparatus of claim 6 further characterized in that said foam has a bulk diffusion rate coefficient between 1×10^{-4} and 1×10^{-7} cm^2/sec.

Amendments to the claims have been filed as follows

5. An apparatus for attenuating radon gas and radioactive decay product diffusion through a structure (10) comprising a shell (22), said shell (22) formed by applying a continuous coating to the surface (12, 20) of the structure (10), characterized in that said shell (22) attenuates gas diffusion through the structure (10) by retaining substantially all the gas in said shell (22).

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